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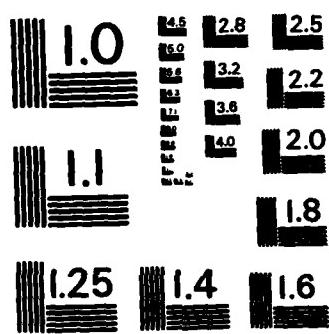
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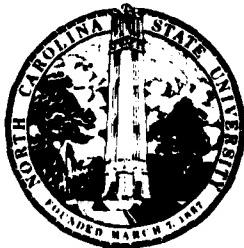
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NCSU-IE Technical Report #85-13

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ANALYSIS AND MODELING  
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NCSU-IE Technical Report #85-13

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Thom J. Hodgson\*  
Russell E. King\*  
James T. McClave\*\*  
James H. Sullivan\*\*\*  
William C. Zegel\*\*\*\*

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\* Industrial Engineering Department  
North Carolina State University  
Raleigh, North Carolina 27695-7906

\*\* College of Business and Administration  
University of Florida  
Gainesville, Florida 32611

\*\*\* Water and Air Research, Inc.  
Gainesville, Florida 32608

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## Analysis and Modeling of Proposed Mining and Beneficiation Process

### ABSTRACT

The purpose of this research was to develop an analytic model of a proposed phosphate mine which could be used to predict the quality of the water within the system throughout the useful life of the mine. The water quality is determined by tracking the concentrations of various chemical ions at key locations in the mining and beneficiation process. The results of the model were used in the evaluation of the environmental impact of a proposed mine.

In this paper we will: describe the features of the proposed process; analyze the process and develop a nonstationary differential flow network model; discuss model assumptions and exogenous driving functions; compare steady-state model results with a laboratory simulation; and, finally, present dynamic modeling results.

*Notes on file*



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## Analysis and Modeling of Proposed Mining and Beneficiation Process

### INTRODUCTION

The purpose of this research was to develop an analytic model of a proposed phosphate mine which could be used to predict the quality of the water within the system throughout the useful life of the mine. The water quality is determined by tracking the concentrations of various chemical ions at key locations in the mining and beneficiation process. The results of the model were used in the evaluation of the environmental impact of a proposed mine.

In this paper we will: describe the features of the proposed process; analyze the process and develop a nonstationary differential flow network model; discuss model assumptions and exogenous driving functions; compare steady-state model results with a laboratory simulation; and, finally, present dynamic modeling results.

### PROCESS DESCRIPTION

The mining and beneficiation process of the proposed mine includes several steps<sup>1</sup>. The major components in the field are two draglines to uncover and remove the ore or matrix. A water slurry of the matrix removed by the draglines is then created and pumped through pipelines to the beneficiation plant. In the beneficiation plant, the phosphate-bearing material is separated from the other matrix materials by several physical separation steps.

These include washing, screening, and flotation. The product may then be dewatered in a drier and shipped off-site primarily by railroad car. The phosphate-depleted material, primarily sand and clay, are pumped to holding areas where they slowly dewater until they can safely support equipment and activities to reclaim the land and return it to productive use. Operation of these facilities will be similar to what has become normal operation of similar facilities at phosphate mines throughout Florida, that is, in accordance with a mining plan, a water management system, and an integrated reclamation plan based on redeposition of phosphate-depleted materials.

The process proposed for use does have some unusual, if not unique, features<sup>2</sup>. First, dewatering of the sand and clay will be accelerated by using a polymeric dewatering agent, mixing the sand and clay in a specified ratio, and using a patented dewatering system to remove a large part of the water before deposition of the sand-clay mix in holding areas. Second, the process will be "zero discharge" in that no water will be discharged to the tributaries of the local waterways unless there is a very unusual series of rain events. This will be accomplished by construction of large reservoirs, rapid reclamation of mined-out areas, and possible use of reverse osmosis (RO) to avoid adding new groundwater to the system.

According to the present design, the only water being transported off the mining site is expected to be by evaporation, with the product being shipped, or possibly by transport with the groundwater. The latter occurs as process waters are routed through the system in unlined ponds and ditches. Seepage may occur which would allow

process waters to enter the surficial aquifer and move with the water already in this aquifer past the mine boundaries.

In an effort to better characterize the quality of the water that may seep into the surficial aquifer, a mathematical model of the process was constructed, and mine operation throughout its life was simulated. In order to make maximum use of available water and have no discharge of effluent, the process has an unusual degree of internal recycle and reuse of water. This leads to concentration of soluble species. The prediction of the levels of these soluble species is complicated by the time-varying input of rain to the system. Thus, a dynamic model using typical rainfall patterns based upon available rainfall records is needed to precisely estimate the quality of the circulating water. The soluble species of concern to Florida Department of Environmental Regulation that may occur in this water, based upon their request for monitoring of phosphate effluent, are fluoride ion, phosphate ion, and hydrogen ion (or pH). Ions that are expected to be present at the highest concentrations are sulfate, bicarbonate, calcium, magnesium, and sodium. Bicarbonate and pH are very difficult to model because of varying buffering capacity of the matrix, natural waters, etc. However, they are mutually dependent and can be adjusted before discharge if necessary. Thus, in our modeling we need only follow the levels of fluoride, phosphate, sulfate, calcium, magnesium, and sodium in the process.

#### PROCESS MODELING

The purpose of the model is to predict the concentration of selected ions at specific points in the process and at specific times

in the future. Water is the primary carrier of these ions. Water enters the system from various sources:

1. With the matrix,
2. As rainfall,
3. As pit seepage
4. As pumpage from shallow wells, and
5. As pumpage from deep wells.

The ions of concern leave the system in several ways:

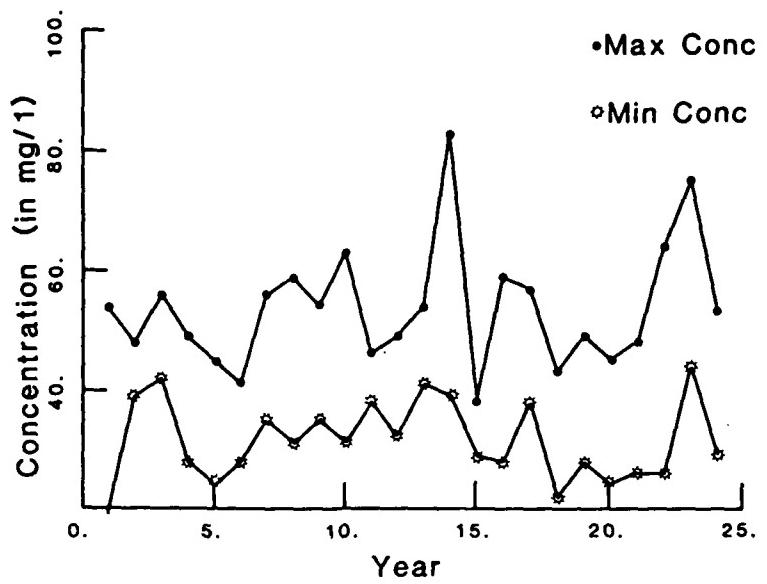
1. With the product(s),
2. With pit seepage,
3. With ditch seepage,
4. With the sand tailings,
5. With the sand/clay mix, and
6. As precipitates.

In addition, water can leave the system by evaporation.

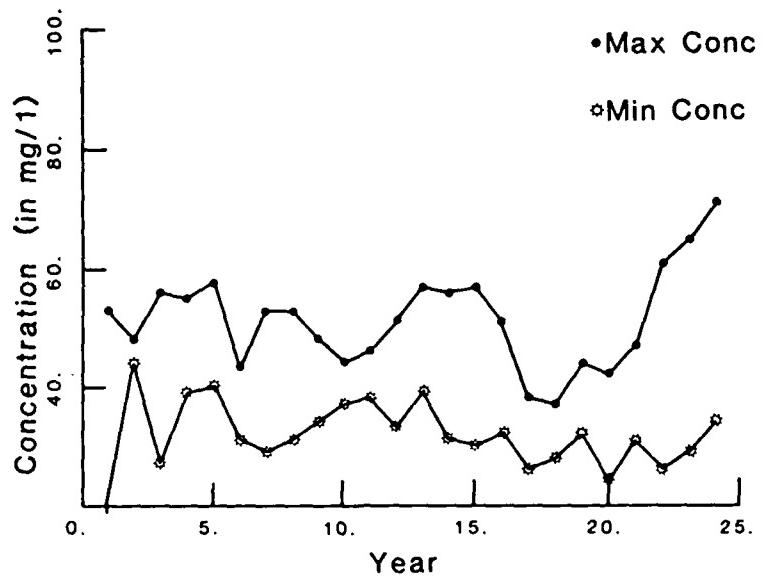
In order to predict the concentrations of the various ions over time, it is helpful to build a mathematical model of the system which can be programmed on a computer. Once on the computer and calibrated, the model can then be used to simulate the operation of the mine/beneficiation plant over the life of the mine.

The system itself is a complex flow network as shown on Figure 1. Ions can enter and exit the system at several points in the network due to chemical additions to the process and precipitation of various solids out of the solution, as well as, the means mentioned previously.

Analysis of the system indicates that the vast majority of the volume of water in the system is contained in the Sand/Clay Pond, Plant Water Pond, and Amine Pond. For any other element of the mine system, water passes through at a very high rate relative to the volume of that element and the volume of water in that element is relatively small and virtually constant (when compared to the potential



SODIUM CONCENTRATION - HIGH RAIN  
Maximum Vs. Minimum



SODIUM CONCENTRATION - LOW RAIN  
Maximum Vs. Minimum

Figure 3 - Yearly Sodium Concentration Range Under Dynamic Conditions

fluctuations in the ponds). As a consequence, the mine system can be modeled as a flow network with the accumulation of water occurring only in the three ponds.

It is desirable within the model to maintain constant data on the concentration of all ions of interest in all activities of the system. This is done within the model by requiring mass balance for all ions of interest for the flow into and out of all activities of the mine network system. It will be seen in the next section that the mathematical model of the system is realized as a set of differential equations. Due to the constant (and very small) volume assumption for most activities of the system, it is seen that the equations describing flow into and out of those activities reduce to linear equations, while the equations describing the flow into and out of the ponds remain as differential equations.

The solution of sets of differential equations with nonstationary driving functions (i.e., rainfall, matrix input, pond evaporation), in general, cannot be done analytically<sup>3</sup>. Consequently, computational methods must be used to achieve solutions. In the present case, a Runge-Kutta approach is taken<sup>4</sup>. A solution, in this case, is the values of pond levels and ion concentrations over time.

Inputs to the model include:

1. Initial pond levels,
2. Initial ion concentrations,
3. Flow rates for various parts of the system (see Figure 1),
4. Rainfall by month over a 24-year period,
5. Evaporation rates by month,
6. Matrix input rates by year
7. Pit seepage rate by year,
8. Seal water input rate, and
9. Well water input rate (controlled by model).

In summary, the mine system is modeled as a nonstationary differential flow network. The accumulation of water occurs only at the three ponds (Amine Pond, Sand/Clay Pond, and Plant Water Pond). The concentrations of ions of interest is maintained through mass balance equations. In the next section, the mathematical structure of the model is developed. Control rules for operating the mine are also discussed.

#### MATHEMATICAL BASIS FOR THE MODEL

The mine system model is built at two levels. At the first level, it is necessary to model the flow of water through the system. At the second level, it is necessary to model the flow of particular chemical ions carried in the water through the system. In this section, the equations for water flow in the system are developed. Then, using the water flow functions, the chemical ion flow equations are developed. At each step the mechanics of the computer model are described.

The following definitions are appropriate:

j,k = Indices of elements (or activities) of the system

(for instance, Station A, washer, Amine Pond, RO unit, scrubber, etc.).

$v_k(t)$  = Volume of the  $k^{\text{th}}$  element (or activity) at time t. This is finite only for the Sand/Clay Pond, Plant Water Pond, and Amine Pond. For all other elements, k,  $v_k$  is considered to be relatively small and constant.

$R_{jk}(t)$  = Flow from activity j to activity k at time t.

$W_k(t)$  = A variable which describes exogenous water input and output rates to activity k at time t. Exogenous inputs and outputs include rainfall into and evaporation out of ponds; matrix into the washer; seal water into the washer; pit seepage into the washer and out of the Sand/Clay Pond; well water input to the Amine Pond and the Plant Water Pond (Station A); and product out of coarse amine, fine amine, washer, and sizer rock float.

$IN_k$  = The set of indices of activities with flow into activity k.

$OUT_k$  = The set of indices of activities with flow out of activity k.

The volume of water at any activity k at any point in time t can be described by:

$$(1) \quad v_k(t) = \int_0^t [ \sum_{j \in IN_k} R_{jk}(t') - \sum_{j \in OUT_k} R_{kj}(t') + W_k(t') ] dt' + v_k(0).$$

Differentiating (1) with respect to t:

$$(2) \quad \frac{dv_k(t)}{dt} = \sum_{j \in IN_k} R_{jk}(t) - \sum_{j \in OUT_k} R_{kj}(t) + W_k(t).$$

For activities k other than the ponds the volume of water is constant; therefore, the derivative is zero and:

$$(3) \quad \sum_{j \in IN_k} R_{jk}(t) - \sum_{j \in OUT_k} R_{kj}(t) + W_k(t) = 0.$$

The process of determining the volumes  $V_k(t)$  and flows  $R_{jk}(t)$  is not as difficult as it would first appear. Most of the flows  $R_{jk}(t)$  are, in fact, fixed and constant over time. The rate of matrix input varies over time, but the effect of changes in matrix input can be easily incorporated into the flows within the system. The RO unit is one source of concern in that it is subject to a certain amount of control. If the Plant Water Pond has insufficient volume to supply the RO unit, then the RO unit is turned off and the wells are turned on for the Amine Pond and the Plant Water Pond. The source of variation which would normally force the RO unit to stop would be the exogenous variables (i.e., lack of rain and/or high rates of evaporation).

Control of the RO unit is accomplished in the following way (refer to Figure 1). Water carrying given concentration levels of the ions of interest enters the RO unit from the Plant Water Pond. Chemicals are added to the RO unit. Clean water flows to the Amine Pond. Water containing the chemicals added to the RO unit and the chemicals removed from the Plant Water Pond input flows to the Sand/Clay Pond.

It is now possible to develop the part of the model which tracks the ion concentration over time. The following definitions are appropriate:

i = Index of the  $i^{\text{th}}$  ion.

$C_{ik}(t)$  = Concentration of ion i at activity k at time t.

$U_{ik}(t)$  = A variable which describes the exogenous ion, i, input (or output) at activity k at time t. Input is achieved, for example, by the input of sulfuric acid in the deoiling activity, which results in addition of a sulfate ion. Output may occur, for example, when the product of the sulfate and calcium ion concentrations exceeds solubility limits and calcium sulfate is precipitated.

$M_{ik}(t)$  = Accumulated mass of ion i at activity k at time t.

The accumulated mass of ion i at activity k at time t can be expressed as:

$$(4) M_{ik}(t) = v_k(t) C_{ik}(t)$$

$$= \int_0^t [ \sum_{j \in IN_k} C_{ij}(t') R_{jk}(t') - C_{ik}(t') \sum_{j \in OUT_k} R_{kj}(t') + U_{ij}(t') ] dt'.$$

Differentiating (4) with respect to t

$$(5) \frac{d M_{ik}(t)}{dt} = v_k(t) \frac{d C_{ik}(t)}{dt} + C_{ik}(t) \frac{d v_k(t)}{dt}$$

$$= \sum_{j \in IN_k} C_{ij}(t) R_{jk}(t) - C_{ik}(t) \sum_{j \in OUT_k} R_{kj}(t) + U_{ik}(t).$$

It should be noted that for activities other than the three ponds,

$$\frac{d M_{ik}(t)}{dt} = 0,$$

since neither water nor ion mass can accumulate there.

Consequently, (5) reduces to:

$$(6) 0 = \sum_{j \in IN_k} C_{ij}(t) R_{jk}(t) - C_{ik}(t) \sum_{j \in OUT_k} R_{kj}(t) + U_{ik}(t)$$

for those activities. It should also be noted that  $v_k(t)$  and  $dv_k(t)/dt$  are obtained from equations (1) and (2) respectively. Therefore, for those activities  $k$  indicating the three ponds, equation (5) can be rewritten as:

$$(7) \frac{dC_{ik}(t)}{dt} = \frac{1}{v_k(t)} \sum_{j \in IN_k} C_{ij}(t) R_{jk}(t) - C_{ik}(t) \left[ \frac{dv_k(t)}{dt} + \sum_{j \in OUT_k} R_{kj}(t) \right] + U_{ik}(t).$$

As a final comment, it should be noted that it is possible that concentrations of various ions might reach high enough levels in parts of the system that precipitate could be formed (for example,  $\text{CaSO}_4$  can be formed from  $\text{Ca}$  and  $\text{SO}_4$  ions if the product of the concentration of the ions exceeds solubility limits<sup>5</sup>). In this case the precipitate,  $\text{CaSO}_4$ , is removed from the system at the rate it is formed and added to the solids.

#### ASSUMPTIONS USED IN MODEL

In operating the mathematical model of the process, certain assumptions were made to establish initial conditions and change points. These were:

1. Plant water pond capacity is a constant  $296,040 \text{ m}^3$  during the first two years. Thereafter, a minimum of  $296,040 \text{ m}^3$  is maintained, but the pond cannot hold more than  $4,613,290 \text{ m}^3$ .

2. Water capacity of the Sand-Clay Pond is 8,511,150 m<sup>3</sup> initially. The minimum is maintained at 3,716,535 m<sup>3</sup> with no maximum.
3. The Amine Pond is a constant 74,010 m<sup>3</sup>.
4. The RO plant operates whenever the Plant Water Pond has more than 296,040 m<sup>3</sup> of water and/or the Sand-Clay Pond has more than 3,716,535 m<sup>3</sup>.
5. When there is no excess water in the system, makeup water from the deep wells goes first to the Amine Pond to replace the RO product and then to the Plant Water Pond if more makeup is needed.
6. Water is transferred between the Sand-Clay Pond and the Plant Water Pond as required to maintain a water balance.
7. All units and nodes are assumed to be completely mixed.
8. The system is initially filled with deep well water.
9. Evaporation removes only water from the system.
10. Average monthly evaporation rates shown below are used every year. (Rates are in cm/month.)

JAN	6.30	MAY	15.95	SEP	11.48
FEB	6.55	JUN	15.60	OCT	8.66
MAR	9.86	JUL	14.58	NOV	6.30
APR	13.79	AUG	13.31	DEC	5.92

11. The flows of water to and from the various sources and sinks are presented in Table 1.

Table 1. Water Flows to and from Various Sinks and Sources Over the 24-Year Life of the Mine

Year	Matrix Water in (m <sup>3</sup> /s)	Pit Seepage in (m <sup>3</sup> /s)	Sand/Clay Water Out (m <sup>3</sup> /s)	Tailings Water Out (m <sup>3</sup> /s)	Pit Seepage Out (m <sup>3</sup> /s)	Catchment Area (1000 m <sup>2</sup> )	Evaporation Area (1000 m <sup>2</sup> )
1	0.119	0.189	0.445	0.006	0	5,532	4,961
2	0.140	0.158	0.364	0.008	0.101	6,665	6,094
3	0.129	0.158	0.164	0.007	0.101	7,798	7,228
4	0.148	0.158	0.383	0.008	0.101	8,932	8,361
5	0.144	0.126	0.166	0.008	0.101	10,065	9,381
6	0.143	0.126	0.221	0.008	0.101	11,198	10,344
7	0.148	0.126	0.334	0.008	0.101	12,331	11,250
8	0.161	0.126	0.289	0.009	0.101	12,897	11,704
9	0.158	0.126	0.318	0.009	0.101	13,181	11,930
10	0.156	0.126	0.318	0.009	0.101	13,181	11,930
11	0.154	0.126	0.273	0.009	0.101	13,181	11,930
12	0.143	0.126	0.252	0.008	0.101	13,181	11,930
13	0.144	0.126	0.222	0.009	0.101	13,181	11,930
14	0.150	0.126	0.206	0.009	0.101	13,181	11,930
15	0.157	0.126	0.290	0.009	0.101	13,181	11,930
16	0.155	0.126	0.285	0.009	0.101	13,181	11,930
17	0.164	0.126	0.416	0.009	0.101	13,181	11,930
18	0.157	0.126	0.421	0.009	0.101	13,181	11,930
19	0.143	0.126	0.299	0.008	0.101	13,181	11,930
20	0.167	0.126	0.353	0.010	0.101	13,181	11,930
21	0.162	0.126	0.317	0.010	0.101	13,181	11,930
22	0.125	0.126	0.120	0.007	0.101	13,181	11,930
23	0.153	0.126	0.314	0.009	0.101	13,181	11,930
24	0.153	0.126	0.238	0.009	0.101	13,181	11,930

Source: Water and Air Research, Inc., 1983<sup>6</sup>.

12. Various reagents are added to the system at particular points to aid in the physical separation. Their contribution to the ions of concern are shown in Table 2 along with other major sources of these ions.

#### RAINFALL

Two different 24-year rainfall scenarios were used in the model, one simulating a wet period and one simulating a dry period. Both were based upon a statistical analysis of the rainfall record of the nearest station with a good historic data base. Using this statistical analysis, two 24-year rain records were generated, one being weighted toward high rainfall years and one toward low rainfall years. Because of the long time period (24 years), the average rainfalls for the wet and dry periods are close to each other (144.7 and 130.3 cm/year, respectively), although specific years show large differences.

#### Steady State Modeling Results

The initial runs of the model were made with constant rain and evaporation to allow comparison with the results of a laboratory simulation. The model contains a more complex network than the laboratory simulation, but the system allows comparison and calibration of the model using the laboratory results. The relevant laboratory results<sup>6</sup> are presented in Table 3 with the corresponding results of the mathematical model.

Generally, there is good agreement between the model and the laboratory results, with the model slightly overpredicting concentrations. The exception to this is total phosphorus. A reason

Table 2. Reagents Added to System and Other Sources of Ions of Concern

Source	Ion					
	Ca <sup>+2</sup>	Mg <sup>+2</sup>	SO <sub>4</sub> <sup>-2</sup>	F <sup>-</sup>	TP*	Na <sup>+</sup>
Rain (mg/l)	0.8	0.4	2	0.01	0.16	0.100
Pit Seepage (mg/l)	0.4	1.9	6.5	0.22	9.5	0.073
Shallow Well (mg/l)	10	1.4	3	0.35	2.1	0.073
Deep Wells (mg/l)	55	14	72	0.74	0.22	0.100
Matrix Water (mg/l)~	0.4	330	6.5	0.22	6.6	0.073
Streams from Washer, Feed Preparation,	225	—	975	undet.	undet.	undet.
Fine Decoiler, and Coarse Decoiler (mg/l)	—	—	—	—	—	—
RO Reject (m <sup>3</sup> /s when operating) (.189 gpm product rate at design)	—	—	1424.30	—	147.87	87.74
Reagent Added to Course FA Float (m <sup>3</sup> /s)	—	—	—	—	—	428.65
Reagent Added to Fine FA Float (m <sup>3</sup> /s)	—	—	—	—	—	1456.05
Reagent Added to Course Decoiling (m <sup>3</sup> /s)	—	—	2907.58	—	—	—
Reagent Added to Fine Decoiling (m <sup>3</sup> /s)	—	—	12,247.2	—	—	—
Sulfur Scrubber on Drier (m <sup>3</sup> /s)	730.2	38.28	1465	—	—	148.32
Species Released in:						
Coarse Decoiling (m <sup>3</sup> /s)	—	—	—	28.71	207.29	—
Fine Decoiling (m <sup>3</sup> /s)	—	—	—	39.60	208.49	—

\*Total phosphorus expressed as PO<sub>4</sub><sup>-3</sup>.

~Quality same as pit seepage except magnesium adjusted for amount dissolved in wash and feed preparation.

Source: Water and Air Research, Inc., 19836.

Table 3. Comparison of Laboratory and Mathematical Model Results

Stream/Species	Laboratory Measurement*	(mg/l of ions of concern)		
		Fine Circuit	Course Circuit	Combined
<b>Sand/Clay Return Water</b>				
Calcium	244 + 46		276	
Magnesium	87 + 18		89.4	
Sulfate	975 + 90		1,025	
Fluoride	1.48 + 0.47		1.47	
Total Phosphorus (as P)	0.18 + 0.08		4.0	
Sodium	45 + 15		41.3	
<b>Deoiling Effluent</b>				
Calcium	—	270	270	270
Magnesium	—	69.1	67.2	68.3
Sulfate	962 + 89	1010	1010	1010
Fluoride	1.77 + 0.56	2.71	2.71	2.71
Total Phosphorus (as P)	8.2 + 3.3	5.0	5.0	5.0
Sodium	—	33.4	31.7	32.7
<b>Rougher Cell Water</b>				
Calcium	—	267	265	267
Magnesium	—	88.8	87.8	88.6
Sulfate	950 + 88	998	988	996
Fluoride	1.83 + 0.58	1.43	1.43	1.43
Total Phosphorus (as P)	2.6 + 1.1	3.7	3.7	3.7
Sodium	—	55.8	50.9	54.9
<b>Amine Recycle Water</b>				
Calcium	—	157	154	156
Magnesium	—	41.1	40.3	40.8
Sulfate	575 + 53	550	540	546
Fluoride	1.96 + 0.62	1.71	1.68	1.70
Total Phosphorus (as P)	2.6 + 1.1	2.5	2.5	2.5
Sodium	—	19.1	18.6	18.9
<b>Sand Tailings Water</b>				
Calcium	—		267	
Magnesium	—		88.6	
Sulfate	1,125 + 104		996	
Fluoride	1.75 + 0.56		1.43	
Total Phosphorus (as P)	2.3 + 0.9		3.7	
Sodium	—		54.9	

\*Includes indication of method at 95-percent confidence level based upon AWWA-AWWA-WPCF "Standard Methods for the Examination of Water and Wastewater."

for the discrepancy, particularly in the Sand/Clay return water, is the slow formation of ortho-phosphate and gradual precipitation of insoluble calcium-phosphorus compounds. Because of the comparatively long residence time in the sand/clay areas, equilibrium values are more closely approached and the levels of phosphorus are reduced. In an actual operating mine, soluble phosphorus will also be taken up by plants which could result in even lower phosphorus levels which are more typical of modern mines. For the purpose of comparing internal streams, the levels of total phosphorus are maintained at the higher levels by the model. These can be adjusted to more reasonable levels based upon solubility equilibria as necessary.

Fluoride levels at other than the Sand/Clay return water seem to be underpredicted except in the deoiling effluent. This may be because of some soluble fluorides in the matrix rather than its postulated release primarily in the deoiling operation with the addition of sulfuric acid. The predicted value for the Sand/Clay return water is in close agreement with the measured value, and the values in other than the deoiler are in reasonable agreement.

#### Dynamic Modeling Results

The next step was to allow the model to be driven by the rainfall, evaporation, and the mining plan to determine what effect these dynamic forces will have upon the concentrations of the ions of concern, particularly in the Sand/Clay return water, which typifies the quality of the majority of seepage into the surficial aquifer. Generally, as rain is added to the system, concentrations decrease, and during dry

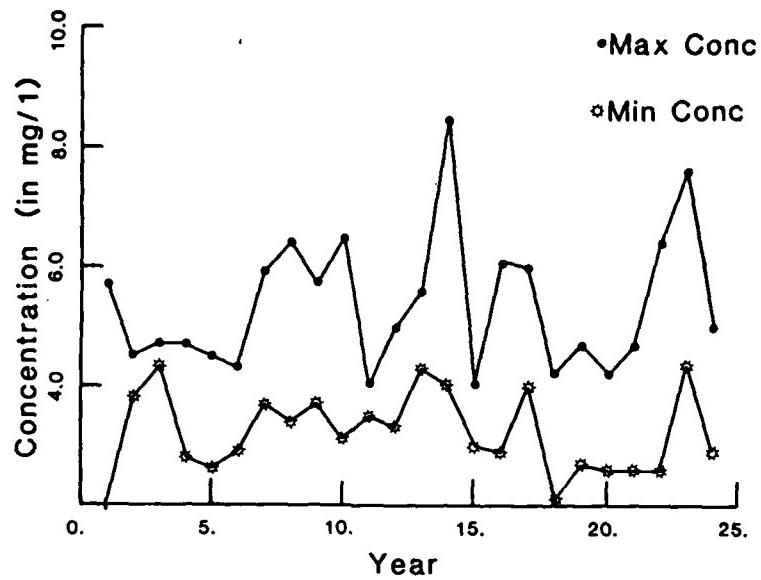
periods, concentrations increase. Figures 2 and 3 present the annual extremes and averages of the concentrations of phosphate and sodium, respectively, under the high rain and low rain scenarios. Plots of the other ions (calcium, fluoride, magnesium, and sulfate) show similar patterns and are, for the sake of brevity, not included.

The results<sup>6</sup> show that the quality of the expected seepage is slightly better for the dynamic simulation than for the steady-state. The introduction of an irregular rain input and other variations in water flows create swings in concentration which are on the average less than steady-state values because high concentrations are capped by the formation of insoluble compounds and their removal from the system by deposition with the sand/clay mix. With the process as currently designed, this is a minor effect estimated at 2-5 percent reduction in ion levels.

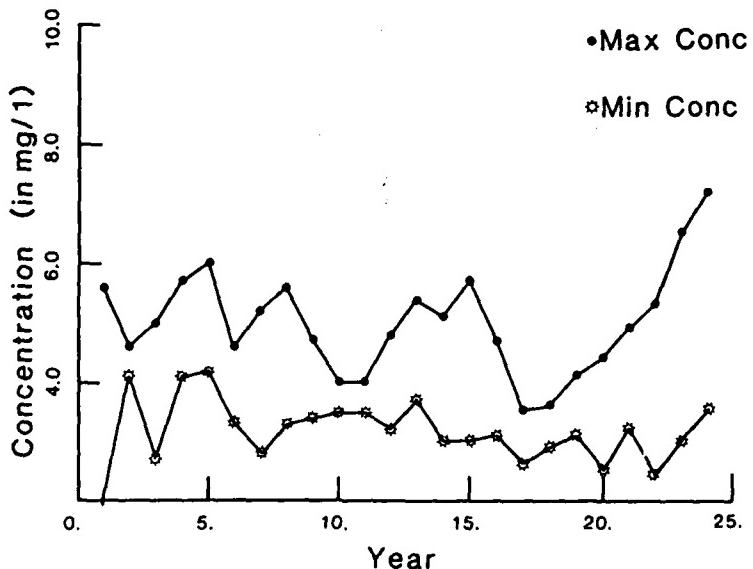
It is interesting to note that the bulk of the process is not strongly affected by the rainfall and other variations, but the Sand/Clay pond and the Plant Water Pond are strongly impacted, both in terms of quality and quantity. The quantity is directly related to the rain/evaporation, and the quality may show 30 to 50 percent variation within a year.

#### CONCLUSIONS

A mining and beneficiation process can be modeled as a nonstationary differential flow network. This network can be solved using Runge-Kutta approximation procedures for simultaneous linear first-order differential equations to yield predicted concentrations of various ions in solution over the useful life of the mine. The model is flexible in that it can be driven by



**PHOSPHATE CONCENTRATION - HIGH RAIN**  
Maximum Vs. Minimum



**PHOSPHATE CONCENTRATION - LOW RAIN**  
Maximum Vs. Minimum

Figure 2 - Yearly Phosphate Concentration Ranges Under Dynamic Conditions

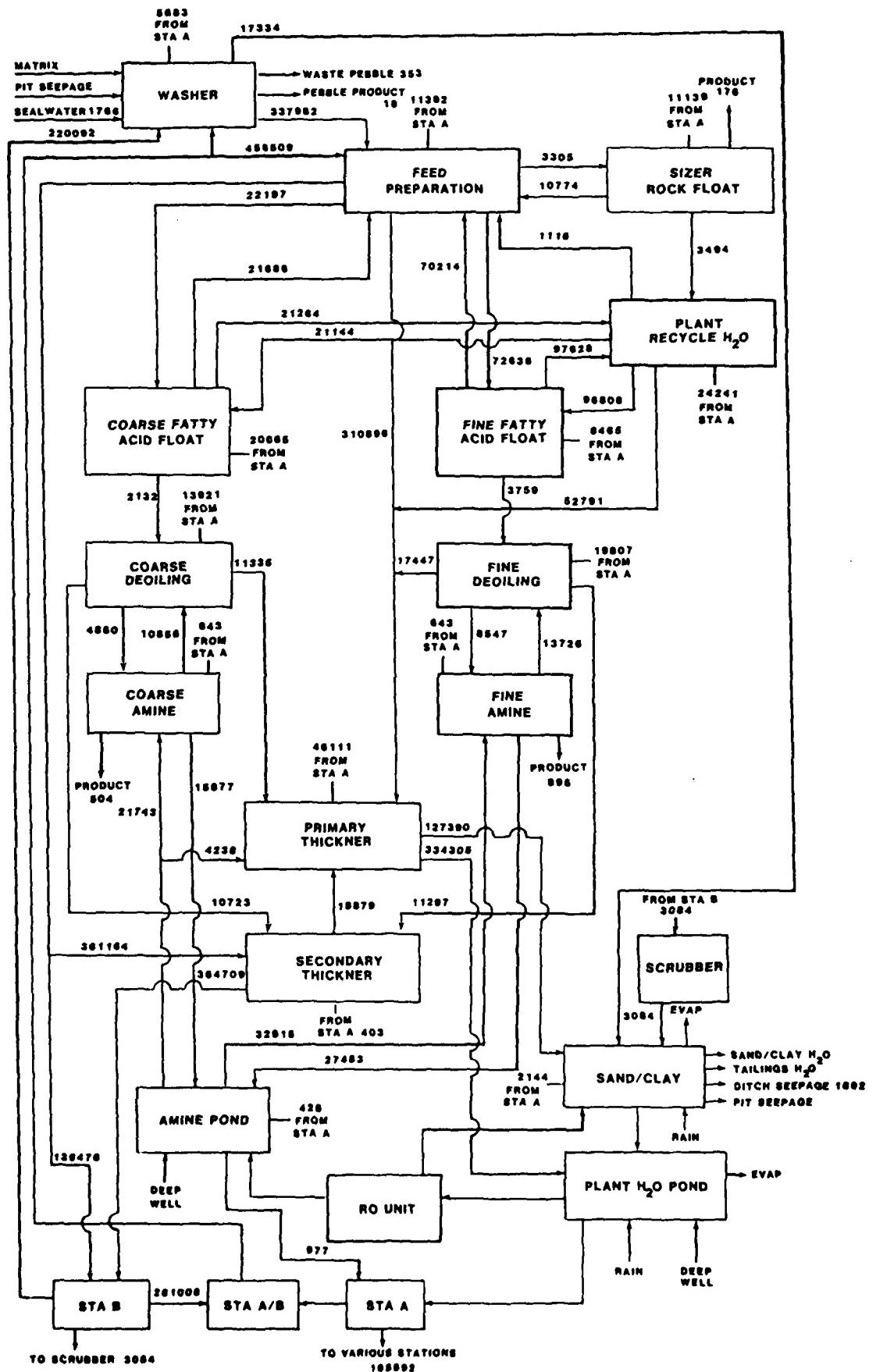


Figure 1 - Flow Network of Mining System (Values represent flow rates in m<sup>3</sup>/s)

any given rainfall and evaporation scenario and mining plan. It allows for tracking of any desired ions and can accommodate ion precipitation. The advantage of such a model lies in the ability to easily modify both controllable and uncontrollable input data and quickly obtain the corresponding effects on the water quality in the system.

The model has been shown to give results in agreement with laboratory simulations and can be used as a predictor of water quality within a mining and beneficiation process. This is useful within existing systems, for example, to evaluate a change in control rules or quantify effects of a predicted dry or wet spells. However, such a model is also useful in evaluating a proposed system in terms of water quality impact as part of the environmental permitting process.

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